King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/MP36 Medical Imaging and Measurement

Summer 2003

Time allowed: THREE Hours

Candidates must answer SIX parts of SECTION A and TWO questions from SECTION B

The approximate mark for each part of a question is indicated in square brackets

You must not use your own calculator for this paper
Where necessary, a College Calculator will have been supplied

TURN OVER WHEN INSTRUCTED

SECTION A - Answer SIX parts of this section.

1.1) An imaging system has a point spread function expressible as

$$P(x,y) = A \quad \text{for } |x| \le x_O,\ |y| \le y_O$$
$$= 0 \text{ otherwise}$$

where A is a constant. Calculate the modulation transfer function for this system.

[7 marks]

1.2) Describe a "first generation" X-ray system for medical computerised tomography. List those features of X-radiation, and its propagation in human tissues, that make it suitable for this type of imaging.

[7 marks]

1.3) Obtain an expression for the intensity of the ultrasound wave $p(x,t) = A\sin(2\pi\{ft - x/\lambda\})$, where A is the (constant) amplitude, f is the frequency and λ is the wavelength of the wave.

[7 marks]

1.4) Describe how, in an appropriate magnetic resonance system, the free induction decay (FID) of the magnetisation of a tissue *slice* through a patient can be measured.

[7 marks]

1.5) Discuss why Tc-99m is a suitable radionuclide to use for single photon emission tomography (SPECT) scanning. Also, indicate any disadvantages it has for medical imaging?

[7 marks]

1.6) A narrow, monochromatic, beam of X-rays is incident on a thin layer of material, consisting of N atoms per cm^3. The interaction of each atom with the photons is expressed by the total cross section, σ cm^2. Derive expressions for the material's linear attenuation coefficient and mass attenuation coefficient in terms of N and σ.

[7 marks]

1.7) Calculate the projection (onto any direction in the plane of $\boldsymbol{r}$) of an annular shaped disk with density,

$$D(\boldsymbol{r}) = C \quad \text{for} \quad a \le |\boldsymbol{r}| \le b$$
$$= 0 \quad \text{otherwise}$$

where C is a constant.

[7 marks]

1.8) Sketch and name three types of collimator, other than the pinhole collimator, used with gamma cameras and indicate how the image relates to the object.

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[7 marks]

SECTION B - answer TWO questions

2) a) Plane waves of ultrasound are incident normally at a planar interface between two media with different characteristic acoustic impedances. Derive expressions for the ultrasound amplitude reflection and transmission coefficients of these waves.

[8 marks]

b) A 5 MHz ultrasound real-time pulse-echo B-mode system is operated with a pulse repetition frequency (PRF) of 2.5 kHz.

i) To what depth in soft tissue can images be formed?

[4 marks]

ii) What is the maximum frame rate if 125 line images are desired?

[2 marks]

iii) If the system is operated in Doppler mode, what is the maximum ('line-of-sight') speed of movement that can be detected within the imaged region?

[6 marks]

Assume that the speed of sound in soft tissues is 1500 m s^{-1}.

c) Briefly describe the processes of envelope detection, time gain compensation, compression and (line) interpolation. State why these processes are incorporated in medical ultrasound B-mode image formation.

[10 marks]

3) a) A single photon emission tomographic (SPECT) system is used to image a bounded region with uniform (radio-) activity enclosed within a patient containing no other activity.

i) Assume that the linear attenuation coefficient for γ - photons of the appropriate energy is constant everywhere within the patient to develop an approximate attenuation correction procedure to be applied to the measured projection data.

[15 marks]

ii) What additional information is needed in order to carry out the attenuation correction, and how would it be obtained in practice?

[3 marks]

b) The point spread function (PSF) of the imaging system in a) is measured to be of the shape

$\mathrm{PSF}(x,y) = A.\exp(-a|x|).\exp(-a|y|)$ with a and A constants.

Calculate:

i) the line spread function (LSF) of the system

[4 marks]

ii) the edge spread function (ESF) of the system

[5 marks]

iii) the phase transfer function (PTF) of the system

[3 marks]

4) a) A proton is placed in a constant magnetic field, $\boldsymbol{B}$, with its magnetic moment, μ , initially at an angle, ϕ, to the field.

i) Show that μ precesses about the direction of $\boldsymbol{B}$.

[8 marks]

ii) Obtain an expression for the magnitude of the Larmor frequency.

[10 marks]

Hint: Use classical arguments and note the following vector identity,
$(\boldsymbol{a} \times \boldsymbol{b}) \times \boldsymbol{c} = \boldsymbol{b}(\boldsymbol{c} \bullet \boldsymbol{a}) - \boldsymbol{a}(\boldsymbol{b} \bullet \boldsymbol{c})$

b) Derive an expression for the fractions of ^{1}H nuclei in the upper and lower energy states, in a constant magnetic field of magnitude B tesla at temperature T ^{0}C.

[9 marks]

c) In a magnetic resonance spectrum, the separation of the main spectral peak due to water and the peak due to lipids is approximately 3 ppm. If the static magnetic field strength of a magnetic resonance imaging unit is 1.5 tesla, what is the frequency shift in hydrogen between water and lipid?

[3 marks]

5) a) State the Fourier Slice Theorem and explicitly validate it for any projection of a two dimensional density function, D(x,y).

[10 marks]

b) An X-ray beam is generated by a diagnostic mammography unit operating at a peak voltage of V kV. Obtain an expression for the maximum kinetic energy, K, of a recoil electron in a Compton event produced by these X-rays. Show that K is proportional to V^{2}, to reasonable approximation. Note that the rest mass of an electron is ~ 500 keV.

[10 marks]

c) Describe how the design of an X-ray mammography unit is determined by the physics of the photon / tissue interaction.

[10 marks]